MERRA
Reanalysis Product Description

1. Intent of This Document

This document is intended for users who wish to compare atmospheric reanalyses, specifically the NASA Modern-Era Retrospective analysis for Research and Applications (MERRA), with climate model output in the context of the CMIP5/IPCC historical experiments. This document summarizes essential information needed for comparing this subset of the MERRA product collections [1] to climate model output. References are provided at the end of this document as additional information.

This NASA assimilation product is provided as part of an experimental activity to increase the usability of NASA's data from model-observation syntheses for the model and model analysis communities. For this purpose, MERRA has been reformatted solely for comparisons with the CMIP5 model. Community feedback to improve and validate the product for modeling usage will be appreciated.

Dataset File Name (as it appears on the ESG): MERRA

Technical points of contact for this dataset:

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2. Data Field Descriptions

CF Variable Name	CMIP Name	Units
Total Cloud Fraction	clt	%
Evaporation	evspsbl	kg m^{-2} s^{-1}
Surface Upward Latent Heat Flux	hfls	W m^{-2}
Surface Upward Sensible Heat Flux	hfss	W m^{-2}
Specific Humidity	hus	kg kg^{-1}
Surface Air Pressure	ps	Pa
Sea Level Pressure	psl	Pa
Surface Downwelling Longwave Radiation	rlds	W m^{-2}
Surface Downwelling Clear-Sky Longwave Radiation	rldscs	W m^{-2}
Surface Upwelling Longwave Radiation	rlus	W m^{-2}
TOA Outgoing Longwave Radiation	rlut	W m^{-2}
TOA Outgoing Clear-Sky Longwave Radiation	rlutcs	W m^{-2}
Surface Downwelling Shortwave Radiation	rsds	W m^{-2}
TOA Incident Shortwave Radiation	rsdt	W m^{-2}
TOA Outgoing Shortwave Radiation	rsut	W m^{-2}
TOA Outgoing Clear-Sky Shortwave Radiation	rsutcs	W m^{-2}
Air Temperature	ta	K

Near-Surface Air Temperature	tas	K
Surface Downward Eastward Wind Stress	tauu	N m^{-2}
Surface Downward Northward Wind Stress	tauv	N m^{-2}
Surface Temperature	ts	K
Eastward Wind	ua	m s^{-1}
Eastward Near-Surface Wind	uas	m s^{-1}
Northward Wind	va	m s^{-1}
Northward Near-Surface Wind	vas	m s^{-1}
omega (=dp/dt)	wap	Pa s^{-1}
Geopotential Height	zg	m

Spatial resolution:

2D fields: 2/3° longitude × 1/2° latitude (540 × 361 grid)

3D fields, except for omega*:* 2/3° longitude × 1/2° latitude × 42 pressure levels

Omega*:* 1.25° longitude × 1.25° latitude × 42 pressure levels (288 × 144 grid)

Temporal resolution and extent: Monthly averaged, from 01/1979 to 12/2011

Coverage: Global

3. Data Origin

The MERRA Collection for the ESG is a subset of monthly mean fields calculated from the more comprehensive MERRA product suite described in the file specification document available from http://gmao.gsfc.nasa.gov/research/merra/file_specifications.php). MERRA is NASA's most recent atmospheric reanalysis for the satellite era [2] using the GEOS-5 AGCM and associated atmospheric data assimilation system (ADAS) (e.g., [3]).

The grid used for MERRA is ½° latitude × 2/3° longitude with 72 vertical levels, from the surface to 0.01 hPa. For the ESG Collection, the 3D fields have been interpolated to 42 pressure levels. All products are from the history file that is produced by the AGCM during the corrector segment of the assimilation cycle (see Section 6).

4. Validation and Uncertainty Estimate

Users of reanalysis data often request a characterization of the quality of and the uncertainty in the fields. Although assimilation theory provides the basis for providing such estimates, few assimilation groups undertake the necessary calculations. They are, in any case, dependent on the underlying assumptions for the background and observational error statistics (see Section 6) and may not be a true representation of uncertainty. While intercomparison with reference data sets is common practice for ascertaining quality, such comparisons are usually restricted to long-term climatological statistics and seldom provide state-dependent measures of the uncertainties involved. One difficulty is that reanalyses like MERRA assimilate as many observations as possible, leaving very few independent observations for validation. The innovations (observation minus background) and analysis increments (analysis minus background) provide some information on the quality of the analyses, as well as on the consistency of the different observations and how they are represented in the analysis. Comparisons with other reanalyses also provides insight into uncertainties, even though no reanalysis can be regarded as "truth", especially in regions of low observation density and for unobserved variables.

Some relevant statistics are provided in [2]. For example, Figure 1 shows the global mean O-F (observation minus forecast or background) and O-A (observation minus analysis) statistics for January 2004 radiosonde temperature observations. The global analysis biases are relatively small (less than 0.2 K) at most levels, with a cold bias (positive O-A) in the PBL and a warm bias in the upper troposphere. Figure 2 shows the zonal mean values of the interannual correlations between monthly-mean quantities from MERRA and ERA-Interim [4] for various quantities during January and July. While the correlations are generally high for dynamical variables such as tropospheric winds and eddy height, they are considerably lower for thermodynamic and cloud-related variables such as precipitation and outgoing long-wave radiation (OLR) (see [2]). The most challenging region for all quantities is obviously the tropics, more so for the near-surface winds than for the upper tropospheric winds.

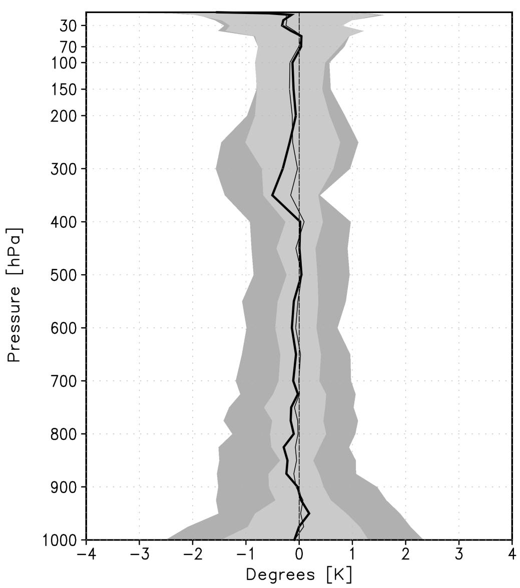

Figure 1: The vertical profile of global mean O-F (thick curve) and O-A (thin curve) residuals (K) for radiosonde temperature observations as a function of pressure level (hPa) during January 2004. The dark and light shading indicate +/-1 standard deviation from the mean O-F and O-A values, respectively.

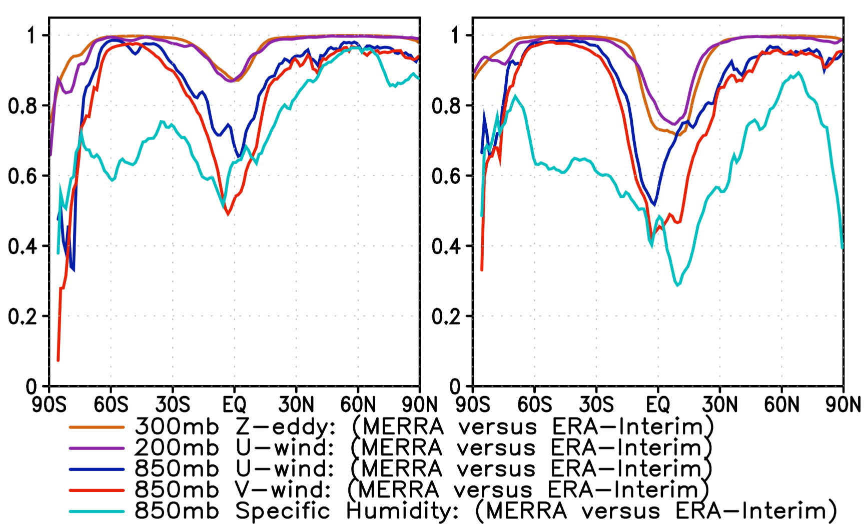

Figure 2: Zonal mean values of the correlation between MERRA and ERA-Interim for various monthly-mean quantities during January (left-hand panels) and July (right-hand panels) for the period 1990 to 2008.

5. Considerations for Model-Observation Comparisons

5.1 Interannual Variability

One of the strengths of the most recent reanalyses is in the representation of interannual variability of the atmospheric state on monthly to seasonal time scales. However, the quality of the climate signal depends on both the variable and the area of interest. Not surprisingly, the interannual variability in analyzed fields, like 500 hPa height (not shown), from different reanalyses in the satellite era is almost indistinguishable. In some other quantities, such as precipitation and Outgoing Longwave Radiation (OLR), reanalyses are still more like each other than they are like the observational estimates.

5.2 Impact of Observing System Changes

Observing system changes often manifest themselves in reanalysis time series by abrupt variations or discontinuities. These impacts from observing system changes, which tend to be amplified by model biases, must be distinguished from real climate variations and pose perhaps the greatest challenge for the next generation of reanalyses.

6. Reanalysis Overview

Data assimilation combines model fields with observations distributed irregularly in space and time into a spatially complete gridded meteorological data set. Reanalyses assimilate historical observations with an unchanging assimilation system. The value of reanalyses lies in their synthesis of a variety of observations from different platforms into a consistent, gridded representation of the atmosphere, including variables that are not observed.

The assimilation analysis, x_a, is obtained by minimizing the scalar cost function

$$J(\boldsymbol{x}) = (\boldsymbol{x} - \boldsymbol{x}_b)^T B^{-1} (\boldsymbol{x} - \boldsymbol{x}_b) + [\boldsymbol{y} - h(\boldsymbol{x})]^T [E + F]^{-1} [\boldsymbol{y} - h(\boldsymbol{x})] + J_C$$

with respect to the control vector, $\boldsymbol{x}$. The background, $\boldsymbol{x}_b$, represents a prior estimate of $\boldsymbol{x}$ from the model forecast and B is its expected error covariance. The vector $\boldsymbol{y}$ contains the available observations, the operator $h(\boldsymbol{x})$ simulates these observations from $\boldsymbol{x}$, and $E+F=R$ contains the expected observation error covariances, including both instrument and representativeness errors. J_C represents additional constraints that can be imposed, such as mass-wind balance and moisture constraints.

In 3D assimilation implementations, the control vector or set of analysis variables, $\boldsymbol{x}$, represents the atmospheric state at the central point in a 6-hour time window as well as predictor coefficients used for radiance bias correction (e.g., [5]) and surface temperatures used to correct model deficiencies at radiance data locations [6]. The forward model $h(\boldsymbol{x})$ transforms the model variables into pseudo-observations. The pseudo-observation value at the observation time is obtained by linear interpolation using background states provided at the analysis time and 3 hours before or after the analysis time. The forward model can be as simple as interpolation from model grid point to the observation location, or as complex as a radiative transfer model for satellite observations.

MERRA uses a three-dimensional variational (3D-Var) analysis algorithm based on the Grid-point Statistical Interpolation scheme (GSI) ([7], [8]) with a six-hour update cycle. MERRA uses an incremental analysis update (IAU) procedure [9] in which the analysis correction is applied to the forecast model gradually, through an additional tendency term in the model equations during the corrector segment (Figure 3).

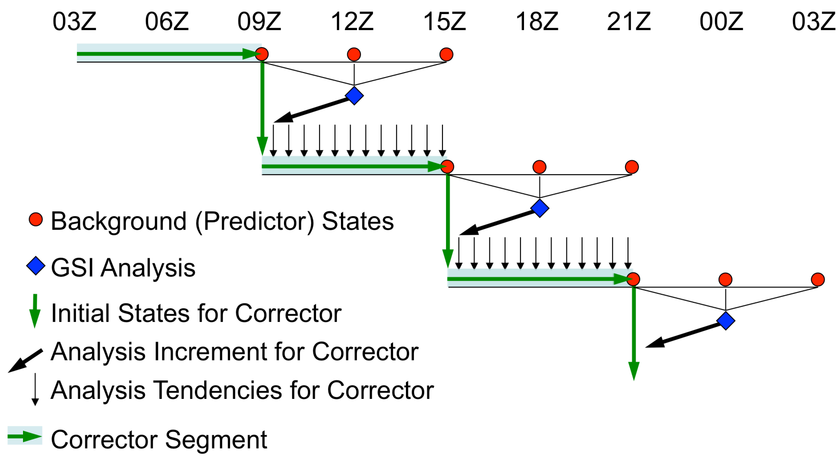

Figure 3: A schematic of the IAU implementation in GEOS-5.

For MERRA, GEOS-5 uses a climatological aerosol distribution generated using the Goddard Chemistry, Aerosol, Radiation, and Transport (GOCART) model with transport based on a previous (GEOS-4) version of the AGCM [10]. The sea surface temperature and sea ice concentration boundary conditions are derived from the weekly 1° sea surface temperature product [11] linearly interpolated in time to each model time-step. The MERRA system also nudges the stratospheric water vapor to zonal mean climatological values based on data from the Halogen Occultation Experiment (HALOE) [12] and the Microwave Limb Sounder (MLS) on the Aura satellite.

7. References

[1] MERRA data is served through the Goddard Earth Sciences Data and Information Services Center (GESDISC): http://disc.sci.gsfc.nasa.gov/daac-bin/DataHoldings.pl.

[2] Rienecker, M. M., and Coauthors, 2011: MERRA - NASA's Modern-Era Retrospective Analysis for Research and Applications. *J. Climate*, **24**, 3624-3648. doi: 10.1175/JCLI-D-11-00015.1.

[3] Rienecker, M. M., and Coauthors, 2008: The GEOS-5 Data Assimilation System – Documentation of Versions 5.0.1 and 5.1.0, and 5.2.0. *NASA Technical Report Series on Global Modeling and Data Assimilation*, NASA/TM-2008-104606, Vol. 27, 92 pp.

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[6] Simmons, A., 2000: Assimilation of satellite data for Numerical Weather Prediction: basic importance, concepts and methods. *Proc. ECMWF seminar on exploitation of the new generation of satellite instruments for numerical weather prediction.* Reading, UK, 4-8 September 2000, pp. 21-46.

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[11] Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. *J. Clim.*, **15**, 1609-1625.

[12] Randel, W.J., F. Wu, J.M. Russell, A. Roche, and J.W. Waters, 1998: Seasonal cycles and QBO variations in stratospheric CH4 and H2O observed in UARS HALOE data. *J. Atmos. Sci.,* **55**, 163-185.

8. Revision History

Rev 0 – 03/04/2012 - This is a new document/dataset.